Unit III: Dynamics

Dynamics is the study of why objects move – it is the study of forces. Kinematics and Dynamics together form what is called Mechanics. Two people were instrumental in the birth of this branch of physics:

Galileo Galilei

- Born in Italy in 1564 and died in 1642
- Remembered for his work in astronomy, mathematics, and physics
- Made the Catholic Church grumpy because he challenged Aristotelian notions about motion by performing experiments
- In 1633 the Inquisition forced him to renounce his theories and placed him under house arrest

Sir Isaac Newton

- Born in England in 1642 and died in 1727
- Invented Calculus
- Came up with three Laws of Motion
- Not friendly, but always acknowledged the work of those before him, especially Galileo:
    - "If I have seen further than other men, it is because I have stood on the shoulders of giants."

Force

A force is push or a pull. Since these can have different magnitudes and directions, force is a vector quantity. Any force acting on an object can change its shape, its velocity, or both.

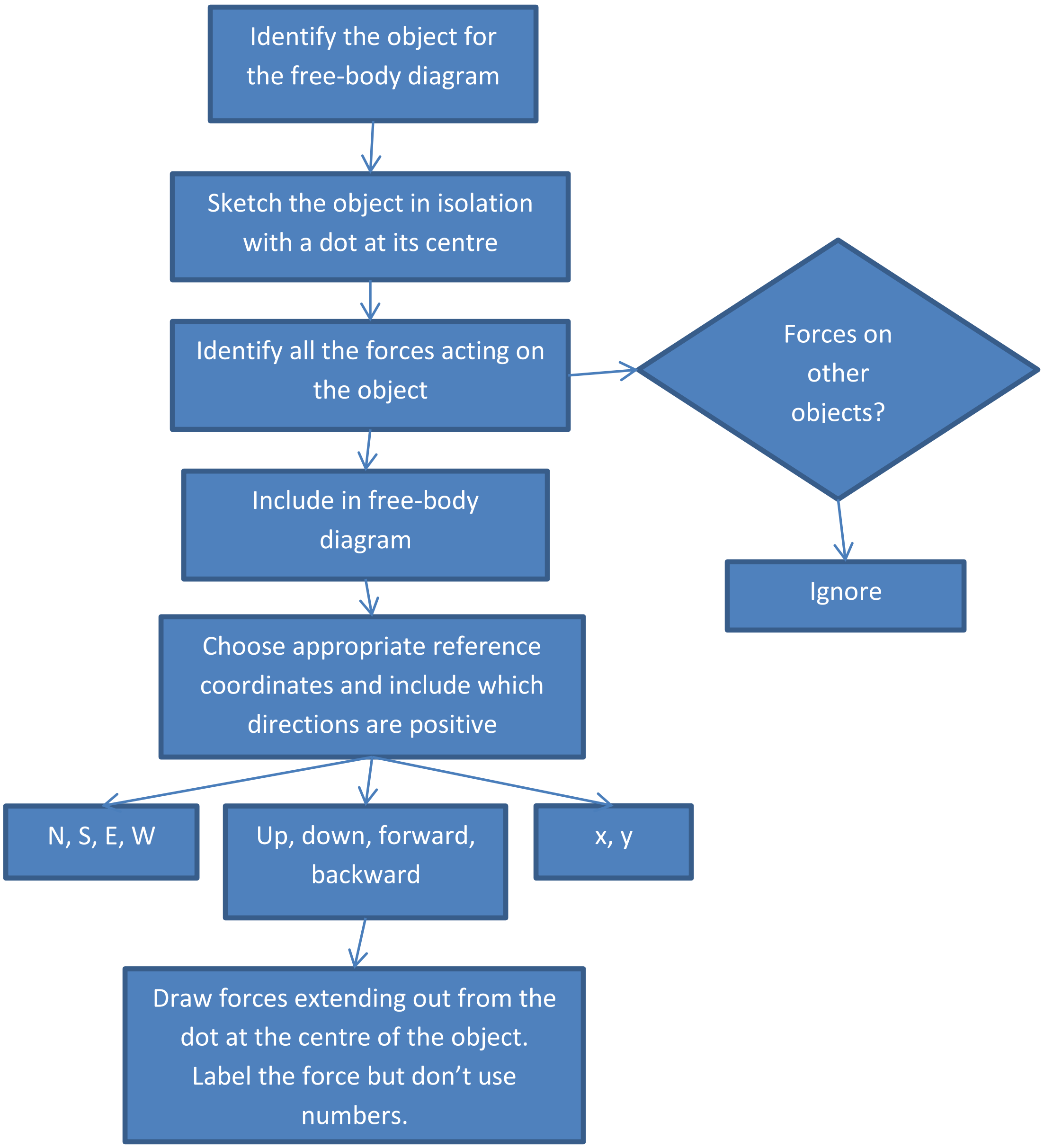
The symbol for force is $\vec{F}$ and the unit is the Newton (N). One Newton is equal to 1 kgm/s^2. Direction is denoted with whatever system is most convenient for the situation.

Free-Body Diagrams

Often, there are many forces acting on an object in any given situation and a system is needed to organize these forces. We will use something called a free-body diagram. A free-body diagram is a sketch that shows the object all by itself, isolated from all other objects.

When drawing a free-body diagram, it is important to denote your reference coordinates that are being used.

Flowchart for drawing free-body diagrams:



Ex. Sketch free-body diagram for a ball being sitting on your palm.

We will see many types of forces acting on an object. Some common that you need to know include:

$$\vec{F}_g = force\ due\ to\ gravity$$

$$\vec{F}_a = applied\ force$$

$$\vec{F}_f = force\ due\ to\ friction$$

$$\vec{F}_T = force\ of\ tension$$

$$\vec{F}_N = normal\ force$$

$$\vec{F}_{NET} = net\ force$$

Each of the above forces will be discussed as they are introduced. When labeling your diagrams, you need to use the same symbols shown above. Capitals and lower case letters do matter.

Ex. Sketch a free-body diagram of a textbook sitting on a table.

The normal force ($\vec{F}_N$) is force on an object that is perpendicular to the contact surface.

Ex. You are pushing a sofa across a rough floor. Sketch the free-body diagram of the sofa.

The force due to friction ($\vec{F}_f$) always opposes the motion of an object and is parallel to the contact surface.

Ex. A tobogganer is sliding down a hill. Sketch a free-body diagram of the toboggan.

Net Force

The net force acting on an object is the resultant of all forces acting on an object. Equilibrium exists if the net force is zero. We find it by finding the sum of all the forces acting on the object.

$$\vec{F}_{NET} = \vec{F}_1 + \vec{F}_2 + \vec{F}_3 + \cdots$$

An object in equilibrium will move with a constant velocity.

An unbalanced force exists when the resultant of all the forces acting on an object does not equal zero. If no external unbalanced force acts on an object, its velocity will remain constant. If an unbalanced force exists, the object will begin to accelerate in that direction.

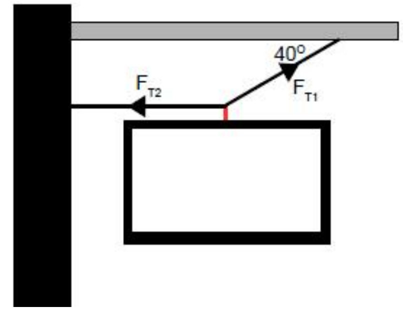
If the forces are parallel to one another, we can just add them together as positive and negative forces. If they are at an angle to one another, we have to add them as components of vectors.

The unit of force is called the Newton in honour of Sir Isaac Newton. It is equivalent to the kg m/s^2.

Ex. Mr. Birrell's Porsche is stuck in a snow drift. Two enterprising students attach two ropes to the Porsche and attempt to pull it out by pulling in the same direction. Mason pulls with a force of 72 N while Caden pulls with a force of 85 N. There is a force due to friction of 55N acting on the car. Sketch a free-body diagram and determine the net force acting on the car.

Ex. As Mason and Caden bravely pull the car, they notice a patch of ice on the road directly in front of them. To keep on pulling without wiping out on the ice, they must begin to pull at an angle as they walk around the ice. Mason now pulls with 72 N [E15°N] and Caden pulls with 85 N [E20°S]. The force due to friction is still 55n. Sketch a new free-body diagram and determine the new net force.

Ex. A 20kg sign is supposed to hang from a pair of wires attached to the wall and a support beam as shown in the diagram. The wires that will be used can withstand a force of tension up to 300 N each. Determine the tension in wire one and wire two and explain any concerns you may have.



The force due to gravity is also called weight. It is defined as:

$\vec{F}_g = m\vec{g}$	Where $\vec{F}_f$ = Weight (Newtons, N, kg m/s^2) m = mass (kg) $\vec{g}$ = acceleration due to gravity (m/s^2)

Newton's First Law (Inertia)

"Every body continues in a state of rest or uniform velocity in a straight line, unless an external force acts on it."

"Every body…"

"…continues in a state of rest or uniform velocity in a straight line…"

"…unless an external force acts on it."

Newton called the idea of an object resisting its state of motion inertia. This is why the First Law is sometimes called the law of inertia. We don't necessarily see it in daily life due to the effects of friction. The first law basically says:

$$If\ \vec{F}_{NET} = 0\ then\ \Delta\vec{v} = 0$$

Ex. Describe the motion of a hockey puck shot down the ice.

Ex. Describe the motion of your binder sitting on your desk.

Ex. Use Newton's First Law to explain why people are injured in head-on collisions in car accidents when they are not wearing their seatbelts.

Newton essentially nicked his First Law from Galileo. Newton gets credit for it because he was the first to actually formally publish it and back it up with mathematical proofs.

Newton's Second Law (Motion)

The First Law says what will happen if there is no net force. The Second Law says what will happen when there is a net force present.

"When an external, unbalance force acts on an object, the object will accelerate in the same direction as the force. The acceleration varies directly as the force, and inversely as the mass."

Break it down:

"When an external, unbalanced force…"

"…accelerates in the same direction as the force…"

"The acceleration varies directly as the force…"

"…and inversely as the mass."

From the above, we get the following mathematical relationship to express Newton's Second Law:

$\vec{F}_{NET} = m\vec{a}$	Where $\vec{F}_{NET}$= Net Force (Newtons, N, kg m/s^2) m = mass (kg) $\vec{a}$ = acceleration (m/s^2)

Ex. What is the net force acting on a 8.35 kg object if it is accelerated at 24 m/s^2?

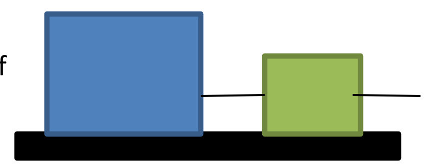
Ex. A lacrosse player exerts an average net horizontal force of 2.8 N [forward] on a 0.14 kg lacrosse ball while running with it in the net of his stick. Calculate the average horizontal acceleration of the ball while in contact with the lacrosse net.

Ex. A person and an elevator have a combined mass of 532 kg. The elevator cable exerts a force of 625 N [up] on the elevator. Find the acceleration of the person.

Ex. Determine the acceleration of the elevator in the example above if the tension in the cable is only 320 N [up].

Ex. A 0.0500 g piece of paper is dropped. While it falls there is a frictional force of 4.71×10^{-4} N. Determine the acceleration of the paper.

Ex. A 31kg box and a 7.0 kg box are attached by a thin wire as shown in the picture. A person pulls on the wire attached to the box on the right. There is a force of friction of 243 N acting on the boxes. Find the force applied to the boxes if they accelerate to the right at 3.78 m/s^2.



Pulley’s change the direction of force. In any pulley problem we do, assume the rope and pulley are massless, have negligible width, and that the rope does not stretch or break. Often, one of the masses will be heavier than the other. This means the heavy mass will move down and the lighter mass move up.

Ex. Two masses are hanging from a pulley. If one mass is 15.25 kg and the mass two is 9.55 kg, determine the acceleration of each mass.

Remember, a pulley can change the direction a force is acting in, but it does not change the magnitude of the force.